

## TAP 407-1: Worked examples – Coulomb's law

### Data required:

$$k = 1 / (4\pi\epsilon_0) = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\text{mass of an electron} = 9.11 \times 10^{-31} \text{ kg}$$

$$\text{mass of a proton} = 1.67 \times 10^{-27} \text{ kg}$$

$$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$

1. What is the force of repulsion between two electrons held one metre apart in a vacuum? What is the gravitational force of attraction between them? By what factor is the electric repulsion greater than the gravitational attraction?
2. By what factor is the electric force between two protons greater than the gravitational force between them?
3. Given the difference in magnitudes of gravitational and electrical forces you've just discovered, why do you feel gravitational attraction from the earth, but no electrical forces?
4. Human beings are electrically neutral objects to a high degree of accuracy. In this question you will estimate the force that would exist between 2 students standing one metre apart if they had just 1% of the electrons in their body somehow removed, leaving them both positively charged. Take the mass of each student to be 60 kg, and as a rough estimate, assume that humans are 100% water. The molar mass of  $\text{H}_2\text{O}$  (the mass of  $6.02 \times 10^{23}$  molecules) is 18 g.  
How many water molecules do the students contain?  
How many electrons are there in a water molecule?  
How many electrons are there in total in each student?  
Taking 1% of these away will leave each student with a net positive charge equal to the charge of 1% of their electrons. What is this value?  
Now calculate the force between the two students, if they are standing 1 metre apart, and comment.

## Answers and worked solutions

1.  $F = kQ_1Q_2/r^2 = (9.0 \times 10^9 \times 1.6 \times 10^{-19} \times 1.6 \times 10^{-19}) / 1^2 = 2.3 \times 10^{-28} \text{ N}$   
 $F = Gm_1m_2/r^2 = (6.67 \times 10^{-11} \times 9.11 \times 10^{-31} \times 9.11 \times 10^{-31}) / 1^2 = 5.5 \times 10^{-71} \text{ N}$   
Electrical force/gravitational force  $= 2.3 \times 10^{-28} / 5.5 \times 10^{-71} = 4 \times 10^{42} \text{ !!!!}$
2. Electrical force is same as with 2 electrons (they have the same magnitude of charge).  
Gravitational force  $= (6.67 \times 10^{-11} \times 1.67 \times 10^{-27} \times 1.67 \times 10^{-27}) / 1^2 = 1.9 \times 10^{-64} \text{ N}$   
Electrical force/gravitational force  $= 1.2 \times 10^{36}$
3. Because even though the Earth has a very large mass, providing a strong gravitational field, both it and you are electrically neutral overall.
4. Number of molecules  $= (60/0.018) \times 6.02 \times 10^{23} = 2.0 \times 10^{27}$   
There are 10 electrons in a water molecule (8 from the O atom and one each from H)  
Thus total number of electrons in student  $= 2.0 \times 10^{28}$   
1% of electrons is  $2.0 \times 10^{26}$  which have a charge of  $2.0 \times 10^{26} \times 1.6 \times 10^{-19} = 32 \text{ MC}$   
(i.e. 32 million coulombs!).  
 $F = kQ_1Q_2/r^2 = 9.0 \times 10^9 \times 32 \times 10^6 \times 32 \times 10^6 / 1^2 = 9.3 \times 10^{24} \text{ N}$   
This is a **huge** force on each student – it is almost the weight of our entire planet!!!